

Towards control of plasma chemistry in low-temperature plasmas

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Low-temperature, or non-equilibrium, plasmas can operate at a range of pressures, from plasma processing at 1-100 Pa pressures to atmospheric-pressure plasmas. What many of these plasmas have in common is that they are efficient sources of reactive species (neutral and ionic), which are critical for the intended plasma effects. Plasma applications span many different fields, e.g. semiconductor manufacturing, thin-film deposition, medicine, green industry and agriculture.

However, selective control over the production of reactive species presents an ongoing challenge and a barrier to the even wider uptake of these devices in applications. The first step towards control is understanding of the complex chemistry in these plasmas, requiring a combination of diagnostics and modelling. Subsequently control methodologies need to be developed as well.

This presentation will focus on Reactive Oxygen and Nitrogen Species (RONS), in particular O₂, OH, H₂O₂ and O₃. These species play a critical role in many open-air, atmospheric-pressure plasma applications as well as low-pressure processing plasmas in O₂ and H₂. Sophisticated diagnostics are combined with fluid and chemistry models to unravel the reaction mechanisms in these plasmas.

An important first step is to measure important RONS directly, for instance atomic O and H using Two-Photon Absorption Laser Induced Fluorescence (TALIF) [1, 2] or advanced actinometry [3], OH via UV absorption spectroscopy [4], and H₂O₂ with Cavity Ringdown Spectroscopy (CRDS) [5]. An example of a measurement of H₂O₂ density distributions in the effluent of two widely used plasma jets is shown in Figure 1. Both jets use RF voltage excitation, but the geometry of the system is different, resulting in differences in both the densities and the profile of the H₂O₂ distribution, indicative of differences in the wider plasma chemistry despite the similarities in the designs of the jets.

For pulsed plasmas, it is critical to not only consider the power-on phase, but also the afterglow period, when understanding and optimising plasma chemistry for applications [1, 6, 7].

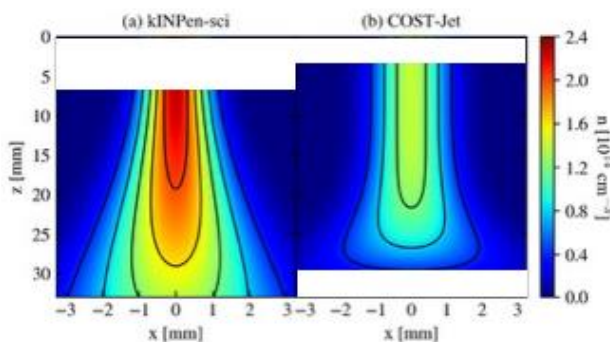


Figure 1: H₂O₂ density distributions in the effluent of two atmospheric pressure plasma jets: the kINPen-sci and COST jets [5].

Figure 2 shows evolution of the H radical density during the HV pulse, but importantly also in the afterglow. The H production is dominated by processes in the afterglow, indicating the importance of this phase in the design and optimisation of plasma chemistry.

As an example of plasma chemistry control methods, tailored voltage waveform methods for controlled ozone production are shown [8]. With tailored voltage waveforms, the ozone density in the far effluent of a plasma jet can be enhanced in comparison to operation with single-frequency voltage waveforms for the same power, marking an important step towards realising the potential of these plasmas for applications.

A further example of the need for a plasma control method is the homogeneity of the plasma chemistry across a large surface. We show that for low-pressure plasmas the plasma uniformity can be increased over a wide range of operating conditions using electrodes with pre-made structures [9].

In conclusion, by developing a thorough understanding of plasma chemistry processes, it is starting to become possible to control, and intelligently optimise, the plasma chemistry for specific applications.

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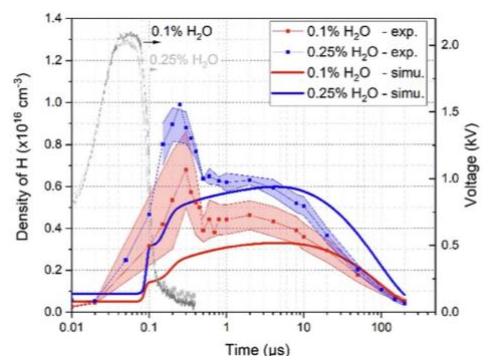


Figure 2: Temporal evolution of the density atomic H in a pulsed discharge in He with H₂O admixtures [1].